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# COGNITIVE PERFORMANCE CHANGE DURING A 6-HOUR HIKE AT LOW TEMPERATURE IN SIMULATED RAIN, AT CONTROLLED WALKING RATES

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COGNITIVE PERFORMANCE CHANGE DURING A 6-HOUR HIKE AT LOW TEMPERATURE  
IN SIMULATED RAIN, AT CONTROLLED WALKING RATES

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## SUMMARY

In response to the need for a greater understanding of the effects of cold-wet exposure on cognitive function, a field study of several physiological, cognitive and behavioral changes induced by cold-wet exposure was undertaken.

Thirty-six male volunteers hiked in a cold-wet environment on a wooded trail for 4 hours. They were protected by non-waterproof light clothing and walked at rates of 0, 3, 4.5 or 6 kilometers per hour. They carried a light-weight instrumentation pack on their back that continuously monitored core (rectal) temperature, skin temperature and oxygen consumption. At approximately 1-hour intervals, the subjects stopped to complete a cognitive test battery. The battery consisted of the Baddeley Reasoning test, the code test, number comparison test and the tapping test. All were derived from the "PETER" battery of the Naval Biomedical Laboratory. In addition, body surface area,  $VO_2$  max and mean skinfold were determined for each subject prior to the hike.

The results indicated that walking rate did not significantly affect performance change during the 4-hour exposure.

With respect to the correlation between temperature and performance, the results were not consistent with several laboratory studies that have related temperature change to cognitive performance change. The present data showed no significant correlation between cognitive deficit and skin temperature, core temperature or oxygen consumption. Furthermore, no correlation was found between cognitive deficit and physical condition ( $VO_2$  max) or body surface area.

The results are interpreted as follows: The changes in cognitive performance that occur in field situations cannot be attributed to mediating physiological changes in skin temperature, core temperature or oxygen consumption. The performance decrements that are observed under the conditions of cold-wet exposure are, therefore, possibly related to modes of attention or to other attributes of personality.



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## INTRODUCTION

Recent assessments of potential threat point to a distinct probability of combat in Northern Europe. In response to this threat, the U.S. Marines have been assigned a "new mission" to operate in Norway, North of the Arctic Circle, in a NATO exercise. After-action reports submitted on recent Marine Corps wet-cold weather exercises have revealed a general unpreparedness to operate in this environment. While steps have been taken to correct existing deficiencies, many medically related questions remain unanswered. There is an urgent need to improve methods for managing cold weather casualties and for reducing cold-related performance impairment. Successful development of such technologies is dependent on an increased understanding of physiological, cognitive and behavioral responses to cold and to their interactions.

The physiological effects of cold have been well documented and guidelines for exposure limits have begun to be established. However, behavioral and cognitive effects, in terms of decreased performance attributable to cold-wet exposure and body cooling are not well understood. As operational environments become increasingly complex and where high-level cognitive functioning is critical, the effects of cold on cognitive performance is of great importance. Guidelines, specifically for military operational environments need to be established and countermeasures developed.

Only a limited amount of information is available regarding the effects of cold on performance and those data are not directly applicable to the Marine Corps's needs. The purpose of the present study was to collect physiological, behavioral and cognitive data from a group of young military age subjects exposed to a cold-wet environment for several hours to determine the relationship between performance decrement and cold-wet exposure over time. In addition, the relationship between performance change and physical fitness and that between performance change and skin and core temperature was then to be determined.

Previous research on performance decrements in the cold suggest at least two general hypotheses concerning decrements, one based on a physiologically mediated change at the level of neural activity in the central nervous system, and one based on psychologically-mediated states of discomfort or distraction. Unfortunately, most reports bring only one or two variables under control, with the result that comparisons of physiological and psychological mediators are not made. These reports have appeared in the literature since the 1930's, yet a clear understanding of the relationship between cold exposure and performance does not yet exist, with the possible exception of the effect of cold on manual performance (dexterity). It is generally reported that manual dexterity is degraded in the cold (Clark, 1961; Lockhart, 1966; Lockhart, 1968), and that the skin temperature at which the decrement occurs is around 12.5°C to 15.5°C. However, even this relationship is complicated by reports that the important thing to consider is the relationship between core and skin temperature when one is interested in complex manual tasks. Kiess and Lockhart (1970), for example, report that if the hands are kept warm and the rest of the body cooled to a mean weighted skin temperature of 25.5°C or below, performance decrements will still occur. This suggests that the discomfort of cold hands is not the critical variable. In fact one implication of this finding is that central nervous system changes attributable to core temperature drops may actually be the mediators of performance decrement seen when complex tasks are involved. The immediate question then is, to what extent does a drop in core temperature affect the central nervous system in such a way that cognitive tasks involving reasoning, memory, or information processing are affected?

One hypothesis that has emerged from studies of cognitive change in the cold is that cold-induced physiological stress causes mental distraction, which subsequently adversely affects cognitive performance (Teichner, 1958). The distraction hypothesis was tested on Navy-qualified SCUBA divers exposed to 3 hours of moderate and cold water by Vaughan (1977). He concluded that a significant distraction effect occurred for performance on higher-order tasks. In an independent study of cognitive performance and vigilance in divers working in cold water, Baddeley, et al. (1975) reported no decrement in reasoning or vigilance, despite a mean drop in rectal temperature of 1.2° F. Using a controlled "cold chamber," Ellis (1982) attempted to differentiate the "distraction" effect from the "arousal" effect of two hours of cold exposure and concluded that either theoretical position might predict the results obtained. Yet other reports support the distraction hypothesis. Bowen (1968) reported losses in "mental capability" on tasks requiring attention and considerable short-term memory.

Clearly, the degree to which cold-induced distraction affects cognitive function in cold water or cold chambers is not known. Tests of cognitive function on land, over long periods of time, have not yet provided data regarding the distraction hypothesis. It was the intention of the present study to start to fill that gap. The general hypothesis was that core temperature and/or skin temperature changes over approximately 4 hours of hiking in a cold-wet environment would correlate with cognitive performance change. In addition, it was hypothesized that physical fitness or fat distribution would correlate with cognitive performance change. These additional variables include  $VO_2$  max as a measure of physical fitness, and mean skinfold and body surface area as measures of fat distribution.

#### METHOD

Subjects. Thirty-six males (mean age 23 years, range 17 to 28) from the University of Victoria volunteered for the study.

#### Procedures

Preparation: Prior to the experimental session, each subject obtained a certificate of good health from a physician and underwent aerobic fitness testing at the University of Victoria. On the evening preceding the experimental session, each subject was requested to refrain from excessive physical/social activity and to follow a specified diet. Prior to the hike each subject completed two forms of the cognitive test battery on two separate occasions to establish a baseline measure. In addition, height, weight, skin surface area, mean skinfold thickness, and  $VO_2$  max were obtained.

Food and water were not available during a session unless absolutely necessary, but was made available immediately after each session. Urination and defecation were strongly encouraged to take place prior to the session and was permitted during the session only following the 10-minute test periods at the end of each hour.

The mean ambient temperatures during the hikes ranged from -1.5°C to +9.5°C. The hikes occurred from December through March, between 4:00 p.m. and 11:30 p.m.

#### Clothing

In addition to controls over wetness, temperature, and exertion, the degree of protection from cold due to clothing worn during the hikes was controlled. A 1.5 CLO value (approximately equal to a man's suit) was maintained for all subjects. During each hike, the subject wore hiking boots provided by experimenter), wool socks, short cotton underwear, jeans, cotton undershirt, cotton long-sleeve shirt, light wool sweater (provided) and a hooded, non-waterproof anorak (provided).

### Instrumentation

On the hike, the subjects carried a 6-kg back pack containing instrumentation and digital read-out devices to record rectal temperature, skin temperature, oxygen consumption and ventilation rate. For the last two variables a partial face mask was worn during the entire session for respiratory gas collection.

Cognitive Tests: Four tests from the "Peters" battery (Kennedy, 1981) were used to measure general cognitive functioning level. Test selection criteria for the present work included: time to administer, reliability over test sessions, magnitude of practice effects, and relevance to the experimental hypotheses. The tests chosen were the Baddeley reasoning test, the coding test, number comparison test and the tapping test. The computer generated tests provided randomly distributed test items for the reasoning test, coding test and the number comparison test. The tapping test, on the other hand, was always the same.

Course: The walking course consisted of a 25-meter trail in a wooded area on Vancouver Island. The terrain was approximately level. At the end of each walking period, the subject was signaled to stop at a designated point on the course to allow the experimenter to read data from the pack. Following that, the cognitive tests were completed. The entire course was covered with a canopy. Beneath the canopy was a sprinkler system that provided periodic rain. Under the wet condition the rain was initiated 45 minutes after initiation of walking and continued to the end of the session.

Session Structure: Subjects were informed whether the session would be wet or dry 5 minutes prior to the "rainstorm." The rate of walking was randomly selected (0, 3, 4.5, or 6 kph) and told to the subject just prior to the session. They were told that they could withdraw from the experiment at any time, but were reminded that hypothermia research is associated with discomfort that is not harmful. In the event that a subject's rectal temperature reached 35°C, the session was terminated. At the completion of the session, or if rectal temperature reached 35°C, subjects were rewarmed with a hot water bath until core temperature reached a normal level. Of the original sample of 36, eight were terminated.

There were 6 test periods during the hike. During these periods the physiological data was recorded and the 4 cognitive tests were completed. The test periods were as follows:

- Test period 1. prior to the hike
- Test period 2. after 100 minutes
- Test period 3. after 160 minutes
- Test period 4. after 220 minutes
- Test period 5. after 60-minute rest period
- Test period 6. after warm up (approx. 60 min)

### RESULTS

The number of subjects in each of the 8 cells of the design matrix (two experimental conditions by 4 walking rates) are given in Table 1. Weather conditions did not permit the completion of the dry walks, with the result that only two subjects were run under each of the dry conditions. The data from the 8 subjects completing the dry condition are included here for descriptive purposes only. The tests for correlations between cognitive performance change and the changes in physiological measures are based on the sample of 28 subjects who completed the wet condition.

TABLE 1  
SUBJECT DISTRIBUTION

	Walking Rate (KPH)				TOTAL
	0.0	3.0	4.5	6.0	
WET	4	8	7	9	28
DRY	2	2	2	2	8
	6	10	9	11	36

#### Walking Rate:

Results from analysis of variance indicate that under the conditions of this study, walking rate did not significantly affect cognitive performance.

The mean number of attempts and number correct for each test are given in Figures 1, 2, 3 and 4. Each Figure shows mean performance at the baseline and the six test periods. These data were collapsed over walking rate into two categories--slow and fast. The slow category consists of the data for the 0 and 3 kph condition, and the fast category consists of the data for the 4.5 and 6 kph condition. In each case the difference between the two curves (number of attempts, number correct) is a direct measure of the error rate. If the two curves overlay precisely, then there were no errors. It can be seen that certain measures of cognitive performance have consistently low error rates, e.g., the coding test (the curves are close together) whereas others, e.g. the Baddeley reasoning test, have relatively higher error rates. Changes in performance over time is also illustrated in the four Figures. Under the wet condition, all tests showed decreases in performance until the 3rd or 4th test period, after which the trend reverses, with levels of performance at the end being approximately equal to the levels in the beginning. The results for the dry condition are quite different. Baddeley reasoning shows increases in performance across the first 3 hours, with a subsequent low level on the 4th or 5th test period. The trend for the coding test results also appears to be the opposite of that observed under the wet condition, with relatively high performance occurring during test periods 3 and 4. These descriptive results are only viewed as a means of generating hypotheses regarding the relation between wet and dry conditions, however, because there were only 8 subjects run under the dry condition.

#### The Relation of Cognitive Performance Change to Temperature Change, Physical Fitness and Fat Distribution

The temperature changes in the periphery (skin) and core (rectal) were hypothesized to be mediators of changes in cognitive performance. If that were the case, then there should be a correlation between temperature changes and performance changes as they occur during the course of the hike. In addition, the other physiological measures are of interest as possible correlates of cognitive performance change. These variables include the  $\text{VO}_2$  max test as a measure of physical

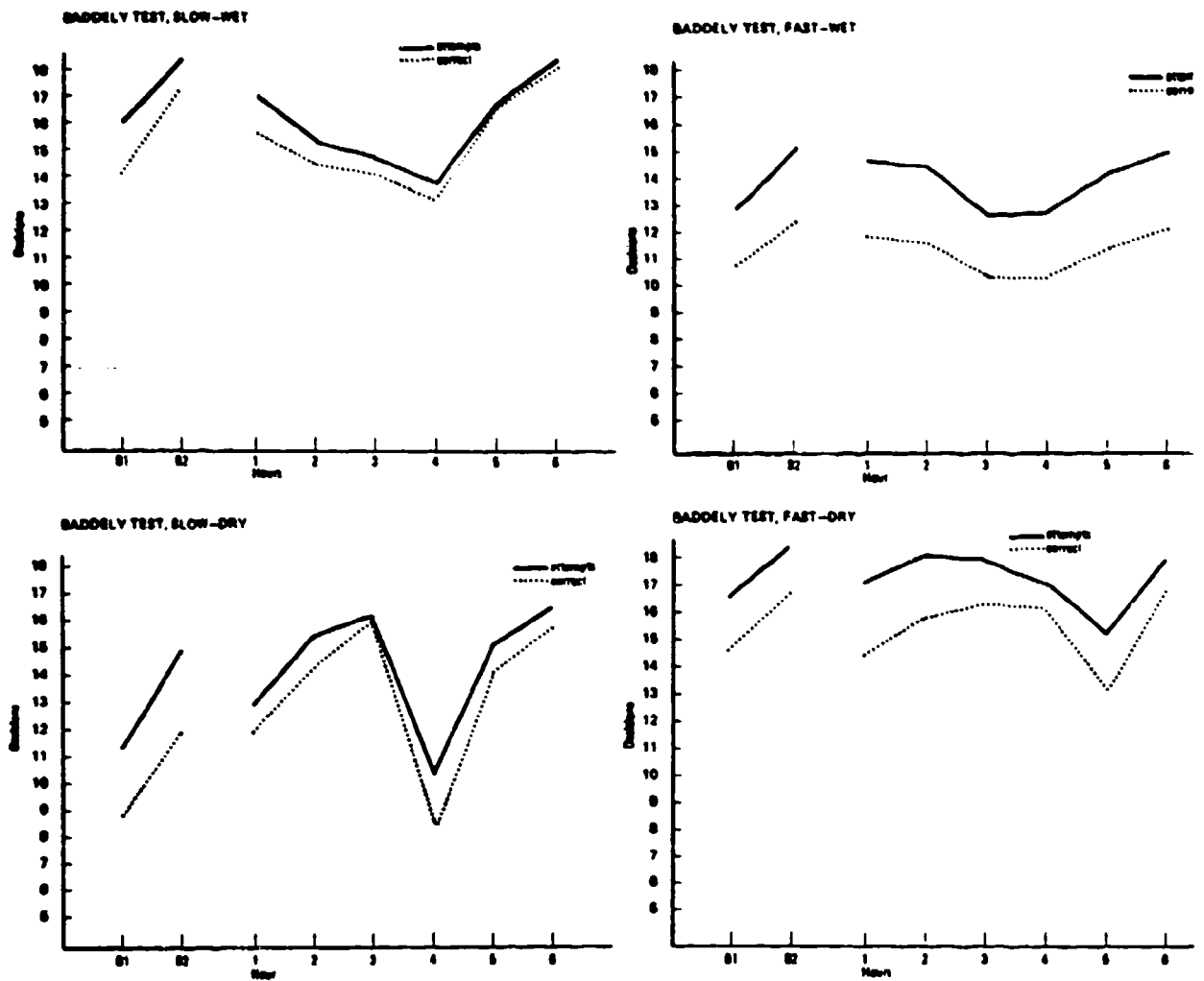


Fig. 1 Group mean performance on the Baddely Reasoning test.



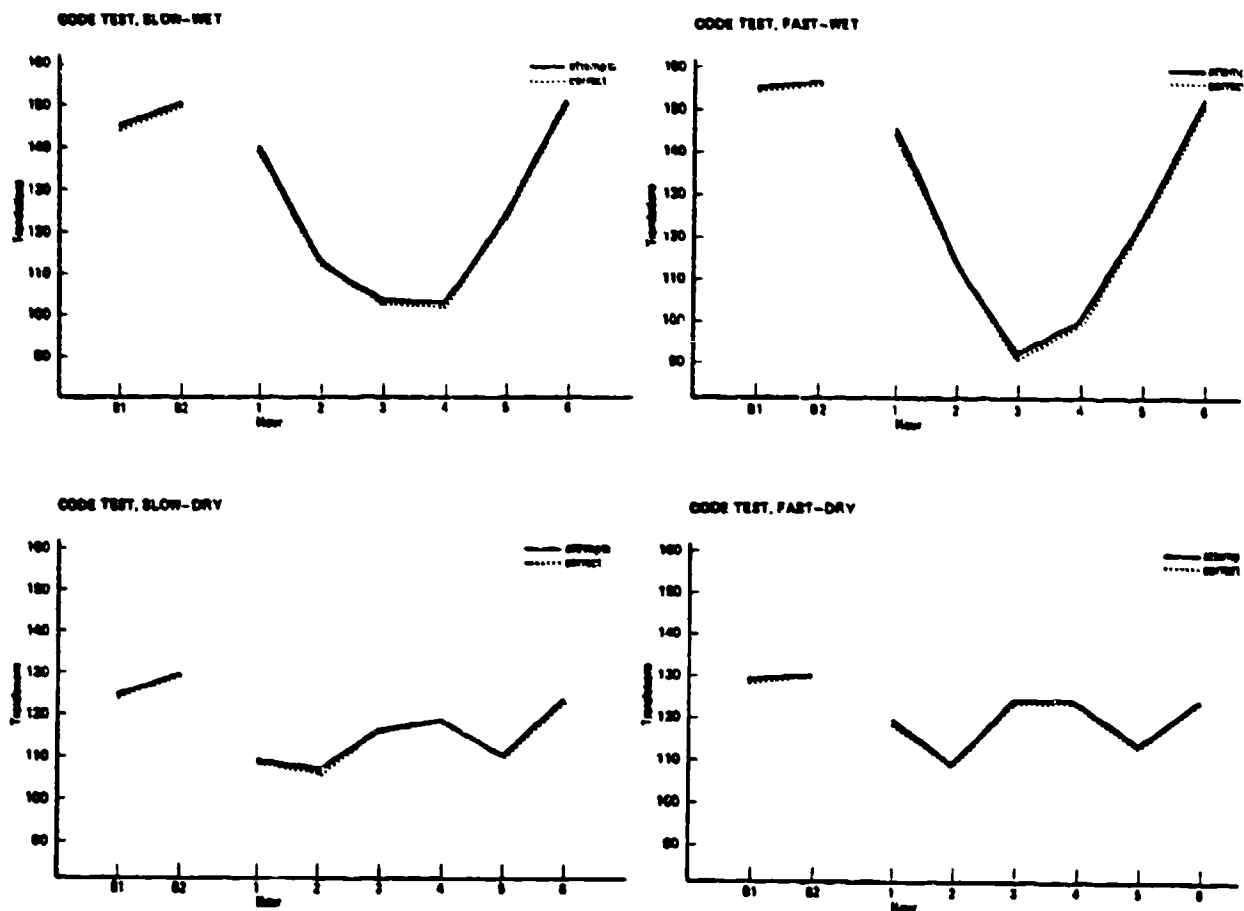


Fig. 2 Group mean performance on the Code test.

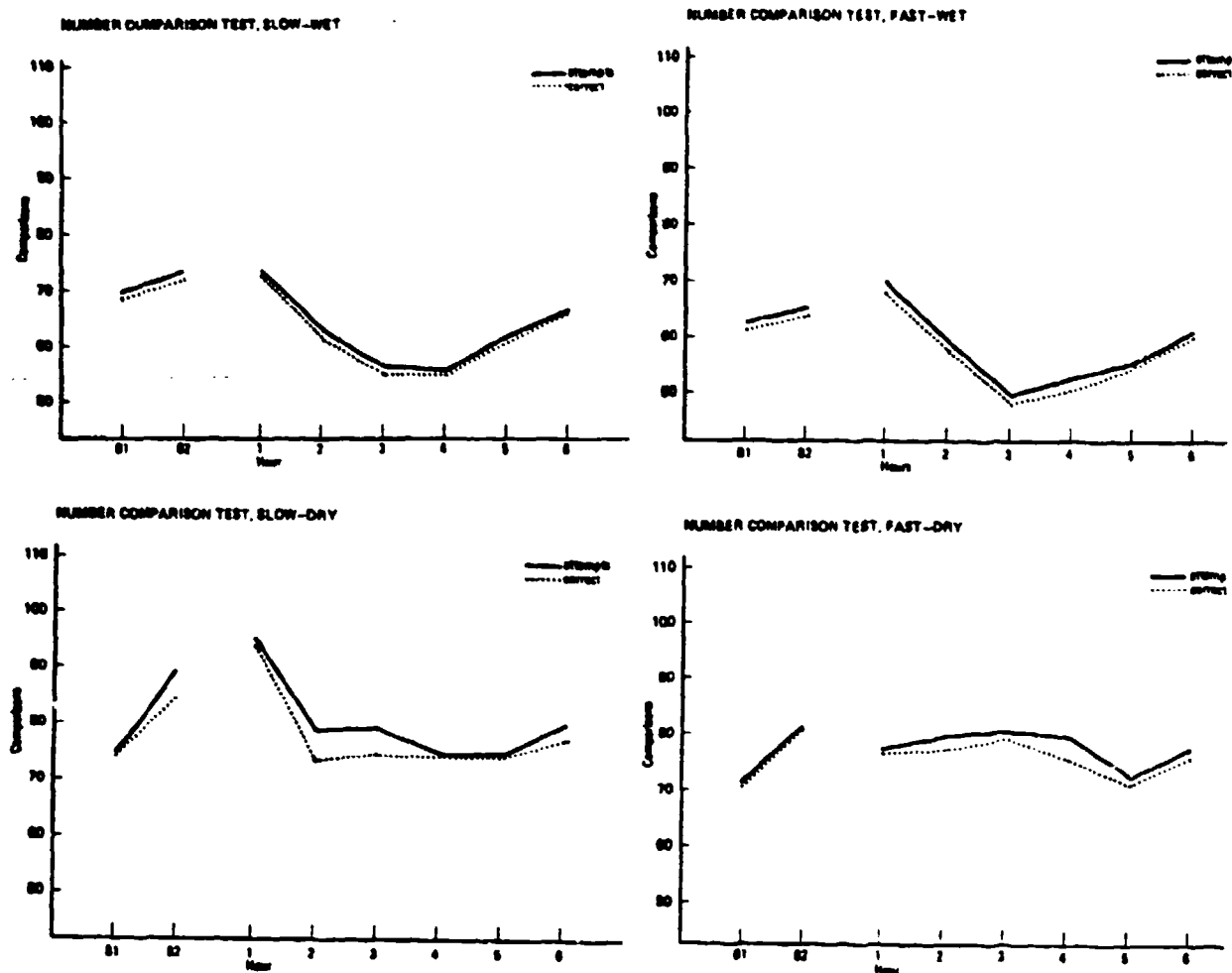


Fig. 3 Group mean performance on the Number Comparison test.

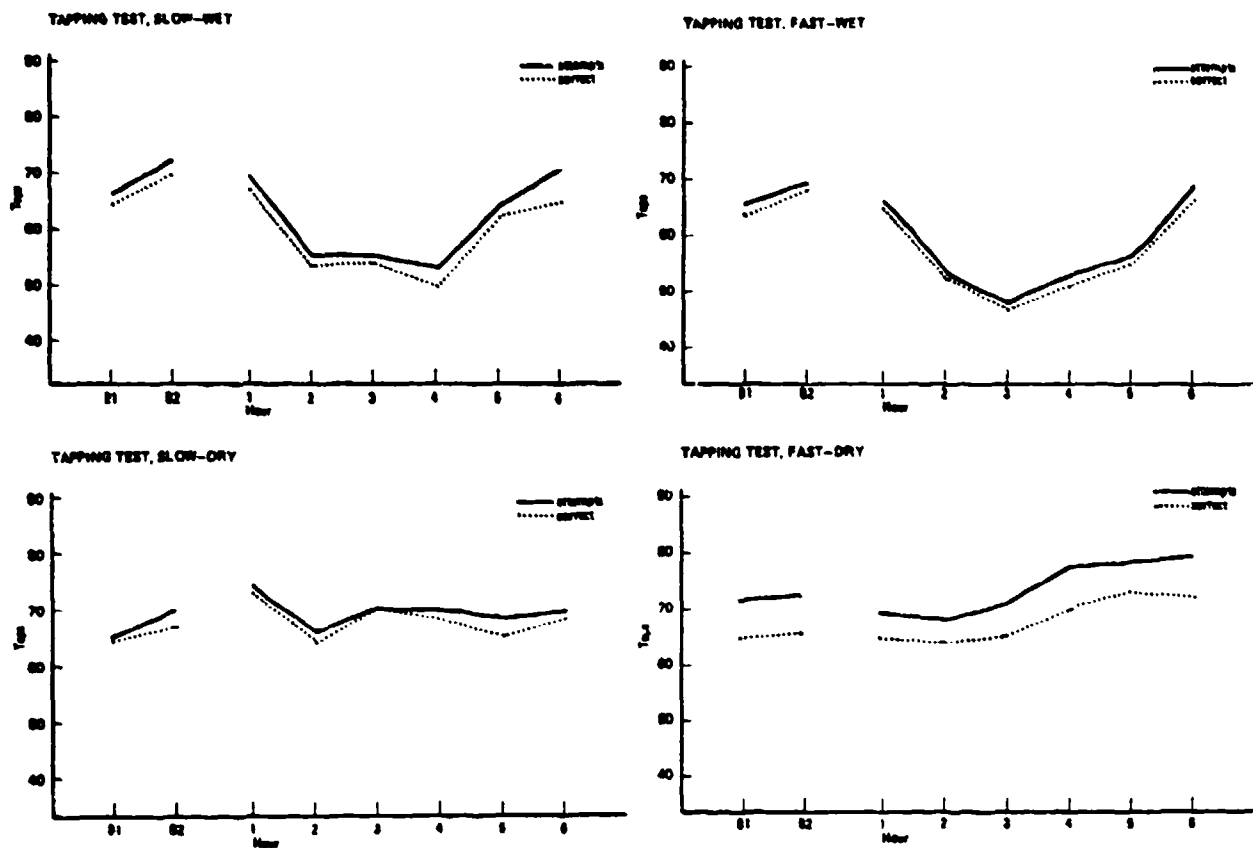


Fig. 4 Group mean performance on the Tapping test.

fitness, and mean skinfold, and body surface area as measures of fat distribution.

For the purpose of determining the relationship between cognitive performance change and temperature change, a measure of performance was computed that was a composite of the number of attempts and number correct. This derived score (D) is typical of the type generally used in multiple choice tasks and takes into account the number of possible alternative responses possible on each trial. If D is the derived performance score, N is the number of possible alternatives, C is the number of correct responses, and A is the number of attempts, then

$$D = C - \frac{(A-C)}{N-1}$$

All test data were transformed to distributions of D and the following results are based on them.

The measure of cognitive performance change under the conditions of continuous wet-cold was based on the first four hours of the hike. This measure of change in performance was the simple difference score between the D score on hour four and hour one. The group means and standard deviations for the 4 cognitive test change scores and the 5 physiological measures are given in Table 2.

TABLE 2

Summary of group means and S.D.s of change in core temperature, skin temperature, and cognitive test performance. Mean and S.D.s of baseline physical fitness and body composition are also given.

Variable	Mean	S.D.	t Value
<b>Change Scores</b>			
1. Core temperature (change)	-.45	.80*	2.92
2. Skin temperature (change)	-8.36	1.44*	30.13
3. Baddeley test (change)	-.83	3.94	1.09
4. Coding test (change)	-42.02	19.55*	11.15
5. Number test (change)	-17.47	8.76*	10.35
6. Tapping test (change)	-16.22	8.65*	9.73
<b>Baseline Measures</b>			
7. VO <sub>2</sub> max	48.16	8.00	
8. Mean skin fold	8.89	2.60	
9. Body surface area	1.82	.12	

\*p<.01 df=27 for change scores

Core temperature change and skin temperature change were obtained at the same time that the cognitive test changes were obtained. The measure of VO<sub>2</sub> max was obtained within 3 days prior to the walk, as was mean skinfold and body surface area.

For the purpose of determining the correlation between the decrements in cognitive performance and physiological measures, a correlation matrix of the 4 cognitive tests and the 5 physiological measures was obtained. The matrix is given in Table 3.

TABLE 3

Correlation matrix of the four cognitive tests, body composition, physical fitness and core and skin temperature changes over the four-hour period

	2	3	4	5	6	7	8	9
1. Core temp. (change)	-.35	-.34	.35	.22	-.04	.24	.23	.00
2. Skin temp. (change)		.44	-.16	.01	.29	-.23	-.01	.09
3. VO <sub>2</sub> max			-.27	-.05	.22	-.27	-.05	-.14
4. Skin fold				.14	-.26	.11	.15	-.17
5. Surface area					-.19	.20	.23	-.10
6. Baddeley (change)						.27	.29	-.01
7. Code (change)							.60	.10
8. Number (change)								-.21
9. Tap (change)								

$r = .306$   $p < .05$

The critical value for a one-tailed test is .306 ( $p < .05$ ,  $n=30$ ). However, using the Dunn-Bonferroni correction for repeated measures changes the critical value to .46. The one correlation that is significant is that between the coding test change and the number comparison test change. All correlations between cognitive tests and physiological measures were not significant.

#### DISCUSSION

In this study, core temperature did not significantly correlate with any of the cognitive test changes, even though 73% of the subjects showed decreases in core temperature. It was also the case that skin temperature change did not predict cognitive performance change. Similar conclusions were reached for the measure of physical fitness and of body fat: they were not related to cognitive performance change in sustained wet-cold.

With respect to the purpose of this study, it appears that first, only three of the four cognitive tests chosen from the PETER test battery are sensitive to 4 hours of sustained wet-cold. Performance on the coding, number, and tapping tests decreased for all subjects. The mean change for the four tests was significantly negative for these three tests as indicated in Table 2. On the Baddeley reasoning test, on the other hand, 37% of the sample showed improvements in performance. One possible reason for this is that the Baddeley test performance may not become asymptotic as readily as the other tests. That conclusion would be consistent with the conclusion drawn by Ellis (1982), that verbal reasoning, contrary to other kinds of cognitive performance, may show improvements under the conditions of laboratory controlled cold exposure.

With respect to the basic question of whether cognitive deficit is attributable to changes in core and skin temperatures, the answer, at least for the conditions of the present study, seems clear; some measures of cognitive performance will show decrements in young healthy males over 4-hour periods of sustained wet-cold, but the deficit is unrelated to body temperature change. Furthermore, it appears that a higher-order cognitive performance, as represented by the Baddeley reasoning test, is less prone to the effect.

Perhaps the answer lies in the way subjects perceive their environment, in the way in which they focus on cognitive tasks, or, to put it another way, on the degree to which their discomfort distracts them during performance testing. This, of course, takes us back to the original question of what causes cognitive deficit. Under the present experimental paradigm it has been reported that cognitive deficit is unrelated to body temperature. The possibility that these deficits are related to attentional or motivational factors is a question that should now be addressed.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  Much evidence supports the idea that cognitive performance decrements associated with cold exposure are attributable to the discomfort experienced rather than to direct physiological effects. Data obtained under laboratory conditions have led to the "distraction" hypothesis of cold-related cognitive performance changes. To test the effects of wet-cold exposure on cognitive performance in a field situation, thirty volunteers each completed a 6-hr hike in ambient		

## 20. Abstract (continued)

temperatures ranging from -1.5 to 9.5 degrees C. Core temperature, skin temperature and oxygen consumption were monitored continuously.  $VO_2$  max, body surface, mean skinfold, height and weight were obtained prior to the hike. Cognitive performance was measured at 1-hr intervals and included the Baddeley Reasoning, Coding, Number Comparison, and Tapping tests.

The results indicate that core temperature changes do not correlate with any of the cognitive performance changes. Furthermore, skin temperature change did not correlate with cognitive performance change. The "distraction" hypothesis was therefore not supported. Based on anecdotal information obtained while running subjects, it is hypothesized that cognitive performance changes in wet-cold are related to personality attributes associated with attention or coping ability.